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EQUIPMENT OF THE AUTOMATIC STATION "LUNA-10" FOR THE INVESTIGATION OF THE γ-RADIATION OF LUNAR ROCK

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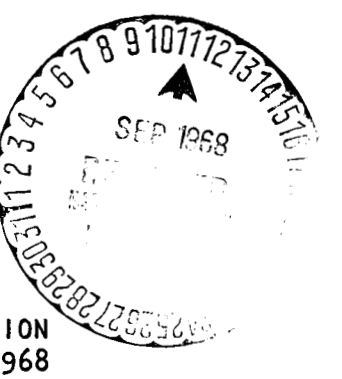

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EQUIPMENT OF THE AUTOMATIC STATION "LUNA-10" FOR THE INVESTIGATION OF THE γ-RADIATION OF LUNAR ROCK

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ABSTRACT. The scintillation γ-spectrometer installed aboard the automatic station "Luna-10" is described. In order to exclude the background of charged particles in the spectrometer sensors, a stratified phosphor, the crystal NaI(Tl) 38 mm long by 28 mm in diameter was used in a container made of scintillating plastic. The amplitude analyzer-spectrometer has 32 capacitance channels of 4096 impulses each. The mean dead time of the analyzer is less than 600 μsec. The nonlinearity of the scale is not more than 1%; the nonregularity of the width of the channels does not exceed 2%. The energy band of the spectrometer is from 0.3 to 3 Mev or from 0.15 to 1.5 Mev. The weight of the spectrometer is 4.5 kg; power required, 2.5 w. The procedure of graduating and calibrating the instrument is given.

Introduction

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The main purpose of installation of the γ-spectrometer on the "Luna-10" automatic station was determination of the type of lunar rock and estimation of chemical composition of the rock on the basis of the characteristic γ-radiation.

As we know, the γ-radiation of lunar rock results from two processes: decay of natural radioactive elements contained in the rock, and nuclear reactions arising upon interaction of cosmic rays with the lunar material. The spectrometry of both forms of γ-radiation allows us in principle to determine the composition of the rock [1].

Determination of the chemical composition of lunar material can be performed using many of the methods used under laboratory conditions. However, γ-spectrometry is apparently not only the most reliable and simplest method, but also one of the few suitable for performance of investigations from lunar orbit. Also, these investigations make it possible to produce information not only on the nature of lunar rocks, but on the radiation environment on the moon.

The absence of any atmosphere on the moon makes it possible to perform measurement of γ-radiation at considerable distance from the lunar surface.

[1] Numbers in the margin indicate pagination in the foreign text.

The intensity of γ-radiation depends only on the solid angle of visibility of the moon from the device. The "Luna-10" circled the moon on an elliptical orbit, the distance from the lunar surface varying from 350 to 1000 km. The intensity of γ-radiation recorded by the spectrometer on the orbit of the satellite also varied, amounting to between 45 and 23% of the intensity of radiation at the surface of the moon.

In measuring the γ-radiation of the moon using a scintillation counter, one must take into consideration the existence of background radiation from charged particles in space. We know that the flux of charged particles (primarily protons) fluctuates over broad limits depending on solar activity. During solar flares, the flux may reach 1000 protons/$cm^2 \cdot sec$. The flux of particles of galactic origin near the lunar surface, according to the data of "Luna-9", was about 5 particles/$cm^2 \cdot sec$. The energy spectrum of these particles extends up to many bev. This factor made it necessary to use a laminated phosphor (Foswich) γ-radiation detector, which excludes the background from charged particles. /266

Measurement of γ-radiation from lunar orbit allowed large regions of the surface of the visible and dark side of the moon to be investigated. During its active existence as a lunar orbital station (about two months), the total volume of information produced by the γ-spectrometer amounted to about 10,000 bits. The preliminary results of investigation of lunar γ-radiation produced using this spectrometer were published in works [2, 3], while a more detailed report is contained in [4].

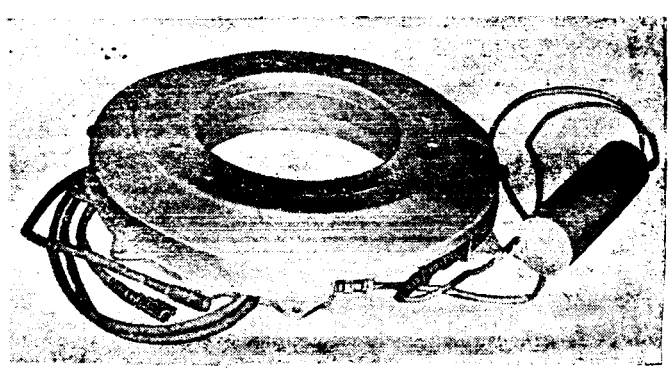

Figure 1. View of γ-spectrometer

The device which was developed, shown in the photograph on Figure 1, consists of a scintillation counter and a multi-channel amplitude analyzer.

The analyzer is made in the form of a toroid with an outer diameter of 372 mm, a height of 68 mm, contained in the sealed portion of the station. For communication with on-board systems, the analyzer has two cables ending in plugs. The transducer is cylindrical in form, 55 mm in diameter by 180 mm length. In the form shown on Figure 1, it is designed for installation in the sealed portion of the station; however, there is another construction variant designed for placement outside the sealed portion of the station. The weight of the analyzer is 3.9 kg, the weight of the transducer is 0.6 kg, and the power consumed by the spectrometer does not exceed 2.5 w.

We present below a description of the principle of operation of the spectrometer units and their principal characteristics. The analyzer is analyzed in more detail in [5].

Scintillation Transducer

Figure 2 shows the scintillation transducer in cross section. As was noted above, the detector consisted of complex phosphor *9*, consisting of an NaI(Tl) monocrystal 28 mm in diameter and 38 mm long, packed in a container consisting of plastic scintillator *1*. In selecting the thickness of the plastic scintillator, calculations of the energy losses of protons at various energy levels in the plastic were performed. It was determined that a plastic scintillator thickness of 3 mm would assure sufficiently reliable shielding over a broad range of proton energies. Elimination of the background resulting from charged /267 particles was achieved by using an electronic circuit which utilized the difference in luminescence time of the NaI(Tl) monocrystal (τ = 0.25 μsec) and the plastic scintillator (τ = 0.005 μsec).

The most effective means of preventing clouding of the hygroscopic NaI(Tl) crystal was found to be installation of a thin glass container *10* between the plastic container and the NaI(Tl) monocrystal. This assured hermetic sealing of the monocrystal. Optical contact between the component parts of the laminar phosphor was assured by usage of vaseline oil or silicone glue. A special reflecting enamel was used to coat the plastic surface of the scintillator everywhere except on the side toward the photomultiplier. Optical contact between the laminated phosphor and the type FEU-16 photomultiplier *4* was assured by using viscous silicone glue. To increase the mechanical strength, a tight rubber collar *2* was placed around the assembled system (laminated phosphor and photomultiplier). The photomultiplier was protected from the influence of weak magnetic fields by permalloy screen *3*. The divider used to supply power to dynodes *8* was mounted on a panel fastened to the base of the photomultiplier. After assembly of the system was completed, it was filled with polyurethane foam and placed in thin aluminum shell *5* for increased mechanical strength. The resolving capacity of the transducer, determined from the energetic radiation line of Cs^{137} with the laminated phosphor described above was no worse than 14%.

Multi-channel Amplitude Analyzer

As was stated above, the energy spectrum of the lunar surface γ-radiation is determined by natural and induced activity. A quantitative determination of the content of natural and cosmogenic γ-radiators requires measurement of the differential spectrum over a broad energy range. This task is performed by the amplitude analyzer, which quantizes pulse amplitudes into 32 groups (channels) of various widths, sorts pulses among the channels and adds the number of pulses in each channel.

The amplitude analyzer consists essentially of a special purpose digital computer fed by the transducer and working in real time. The analyzer consists /268
of the input, memory, arithmetic and output devices. A functional diagram of the analyzer is shown on Figure 3.

The analyzer uses a dynamic memory device consisting of a metal ultrasonic delay line with quartz crystals transducing electrical signals to acoustic waves and vice versa. Information is entered into the line in the form of sequential binary codes. The delay factor of the line used was about 500 μsec; therefore, with a cycling frequency of slightly over 1 MHz, 32 words of 16 bits each (512 bits) could be recorded in the line.

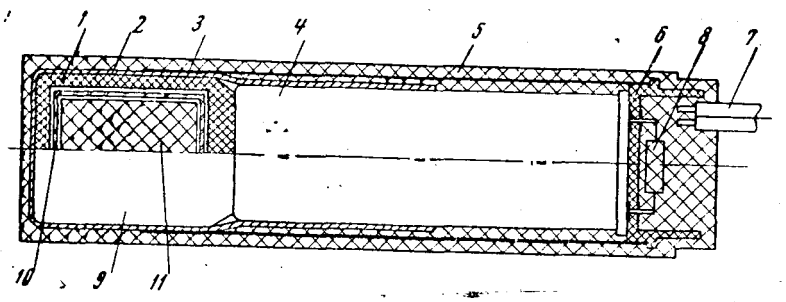

Figure 2. Schematic Cross Section of Transducer: 1, Plastic scintillator container; 2, Rubber collar; 3, Permalloy screen; 4, Photomultiplier; 5, Polyurethane foam; 6, Panel; 7, Cable; 8, Dynode power supply divider; 9, Laminated phosphor; 10, Glass container; 11, NaI(Tl) monocrystal

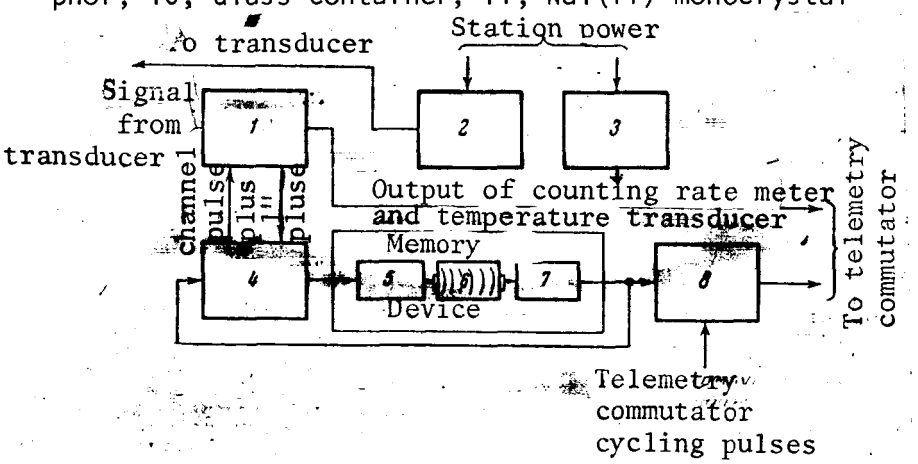

Figure 3. Simplified Functional Diagram of Multichannel Amplitude Analyzer: 1, Input device; 2, High voltage power supply; 3, Low voltage power supply; 4, Arithmetic device; 5, Exciter; 6, Ultrasonic delay line; 7, Amplifier; 8, Output device

The beginning of an operating cycle of the memory device is determined by a start pulse which is automatically recorded after a certain time interval following application of power to the instrument. The start pulse is detected at the output of the line by its length. After the start pulse has been detected, a new operating cycle of the cycling pulse generator begins, assuring strobing of the information recorded.

Of the 16- pulses in each word, only 12 are used to record useful information (Figure 4), so that the capacity of the analyzer channel is $2^{12} = 4096$ events. The other four pulses are service pulses.

If no pulses are received from the transducer during a memory device cycle at the input of the analyzer, the information is written into the line without changes. When a pulse arrives from the photomultiplier, the input device sends to the arithmetic device a pulse indicating "add 1" ("plus 1") to the channel whose number is proportional to the pulse amplitude. The arithmetic device adds one to the number of pulses recorded in this memory channel. Thus, after a certain period of time is passed, the distribution of pulses by amplitude (i.e., the distribution of γ-quanta by energy) can be measured.

The input device of the analyzer includes an attenuator with an attenuation factor of 2, controlled by a trigger. If a special command is transmitted through the radio line, the trigger flops, switching the attenuator. This makes /269
it possible to change the energy range of the spectrometer by a factor of 2. The sensitivity of the analyzer in these two ranges is 10^{-10} and $5 \cdot 10^{-11}$ coul/Mev.

As we can see from Figure 4, there is no channel pulse before the first channel of the memory device. Therefore, information from the scintillation transducer is not recorded in the first channel of the memory device. This allows the first channel of memory to be used as a timer channel: pulses are recorded in this channel with a separation interval of 10 sec from an on-board crystal controlled oscillator. The analyzer also includes a device to halt spectral measurement in case any of the measurement channels is overfilled. When this occurs, the timer channel records the time required for spectral accumulation from the moment recording is begun until overflow occurs.

In spite of the fact that information in the analyzer is represented in digital form, for a number of reasons it was found to be convenient to transmit the information through an analog telemetry commutator, for which a group of neighboring channels was set aside in the commutator. For each cycle pulse, which is the commutator within the group, the contents of one-fourth of one analyzer channel (three bits) are output to the register, then to the digital-analog converter and further to the telemetry channel, and the following quarter channel pulse is erased. This makes it possible to locate and transmit the following three bits with the following cycling pulse from the commutator, etc. At the end of this group of neighboring channels, output is halted and resumed only during the next commutator cycle. After all quarter channel pulses are erased, they are automatically recorded once more, and the output can be repeated.

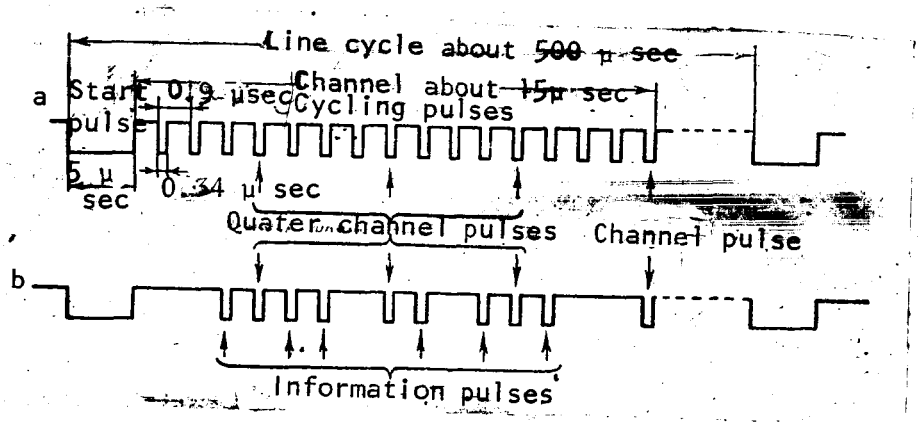

Figure 4. Time Diagram of Pulses in Analyzer: a, Cycling pulses; b, Structure of word, using first the channel as an example. The code recorded is 001110101100 = 860

The error in the analog telemetry channel is rather low, and allows transmission of a considerably greater number of levels than eight. Therefore, the probability of error in transmission of the octal codes is low, and the necessity of repeated output usually does not arise.

In addition to the units which we have described, the analyzer contains a stabilized power supply, a high voltage stabilized converter for the photomultiplier, a logarithmic input pulse counting rate meter, and a temperature transducer.

Methods of Calibration and Standardization

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In order to determine the content of natural radioactive elements in lunar rock, it was necessary to perform standardization of the γ-spectrometer.

First of all, the spectrometer scale was adjusted in the range of interest, up to 3 Mev (or up to 1.5 Mev). Then, using the usual method, the spectrometer was calibrated on the energy axis with photopeaks of the lines of known γ-radiators. Figure 5 shows an example of one calibration graph.

The measurement of standard γ-spectra was performed in 4π-geometry using specially prepared standards of quartz sand in which a certain quantity of the corresponding natural radioactive element (K, Th and U) was included. The uranium and thorium standards contained equilibrium quantities of the daughter products of radioactive decay.

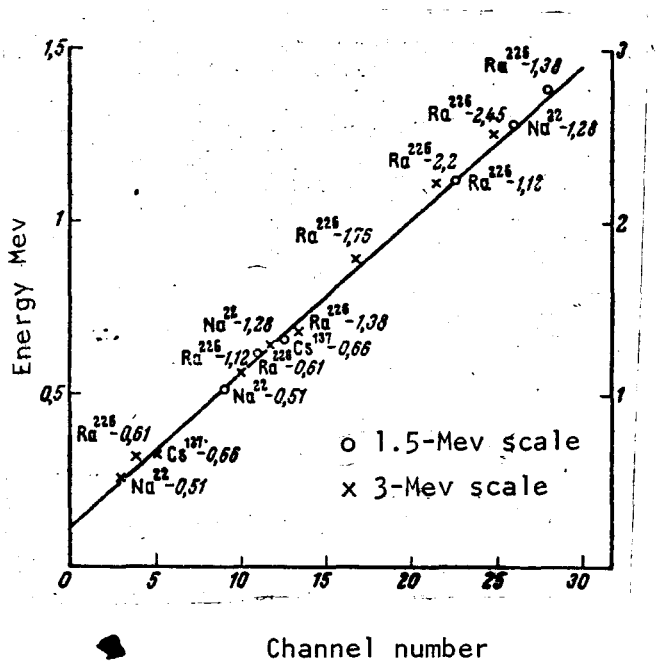

Figure 5. Spectrometer Calibration Graph

Also, standardization of the spectrometer was performed in 2π-geometry on natural mountain massifs in Karelia and Armenia. Determination of the content of K, Th and U in the rocks used for standardization of the instrument was performed by a radiochemical method, after mean samples were taken in the measurement regions.

Figure 6 shows the γ-spectra of the standard samples measured using the spectrometer which we have described. The spectra show the following peaks rather clearly: 1.45 Mev, belonging to K^{40}; 0.9, 1.6, 2.2 and 2.62 Mev, belonging to Th^{232} and its decay products; 1.12, 1.76 and 2.2 Mev, belonging to U^{238} and its decay products.

Figure 7 shows one spectrum measured by "Luna-10" in orbit around the moon, from which the background noise from the interaction of cosmic particles with the construction materials of the station has been subtracted.

This spectrum shows peaks with energies of 0.84, 1.01, 1.38, 1.78 and 2.62 Mev, resulting from interaction of cosmic particles with the lunar rock.

Using the standard spectra, as well as data [6] on the content of K, Th and U in terrestrial rock, the γ-radiation spectra to be expected on the moon, recorded by this device from the orbit of the satellite (H = 600 km) if the lunar rocks correspond to terrestrial rock and rocky meteorites in their content of natural radioactive elements were calculated. These spectra are shown on Figure 8. The upper and lower boundaries of the shaded areas correspond to the maximum and minimum content of natural radioactive elements in the given types of rock.

As follows from the results of measurements of γ-radiation of lunar rock performed by the "Luna-10" [4], the actually measured γ-radiation intensity is higher than the radiation level measured even over acidic terrestrial rocks (granites). However, no less than 90% of this radiation results from cosmic rays, only 10% belonging to natural radioactive elements contained in the lunar rocks. A comparison of the intensities of γ-radiation measured over various regions of the lunar surface with that measured over terrestrial rock gives us

some reason to assume the existence of basic and ultrabasic rock on the moon, and to exclude the existence of acidic rock.

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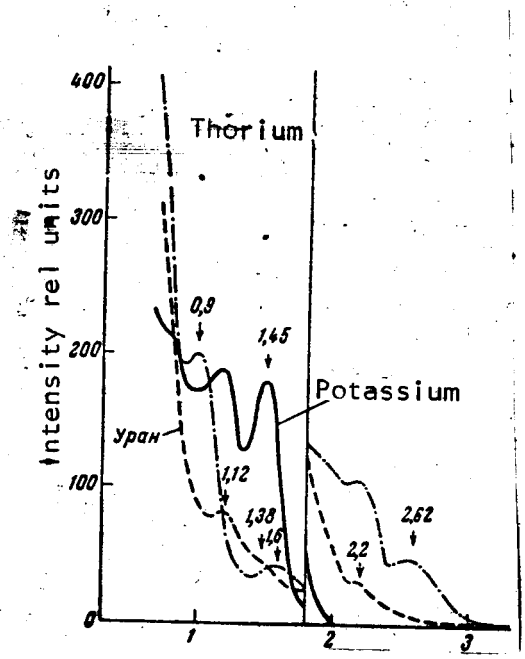
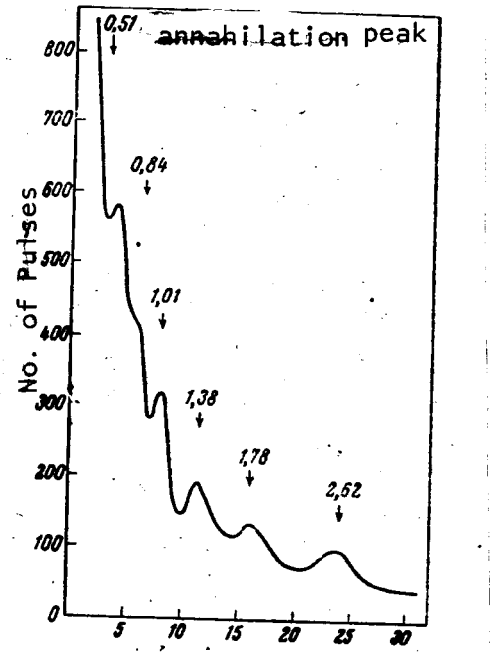


Energy, Mev

Figure 6. γ-radiation Spectra of K^{40}, Th^{232} and U^{238} in Equilibrium with Daughter Products. Scale to right of vertical axis increased by factor of 5



Channel number

Figure 7. γ-radiation Spectrum Measured by "Luna-10" After Subtraction of Background, Resulting from Interaction of Cosmic Radiation with Material of Station. Spectrum accumulation time 600 sec

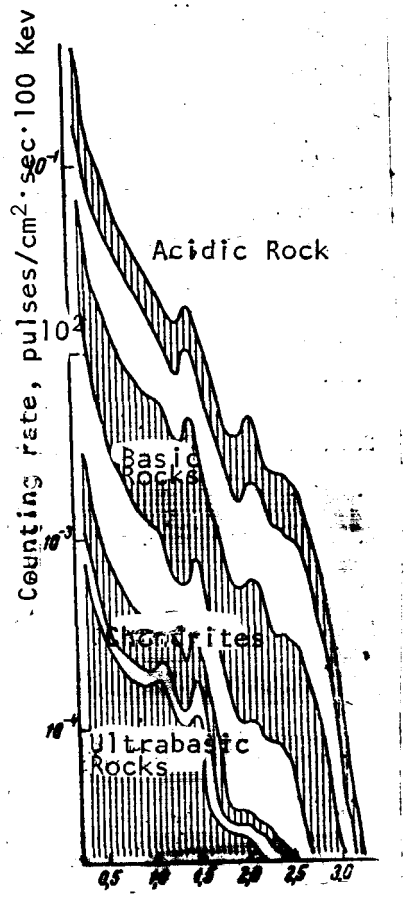


Figure 8. Spectra of γ-radiation Which Would Be Produced by Satellite Orbiting the Moon (H = 600 km) from γ-radiation of Lunar Rocks with Relative Contents of K, Th and U Corresponding to Contents in Primary Types of Terrestrial Rock

In conclusion, the authors wish to express their gratitude to V. K. Andreyev, M. Ye. Glushkovskiy, O. A. Karpukhin, L. N. Myasnikova, V. P. Rakcheyev, who took part in the development and calibration of the instruments, as well as to G. M. Chernov, F. F. Kirnozov and B. M. Andreychikov, who participated in the calibration of the instruments.

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